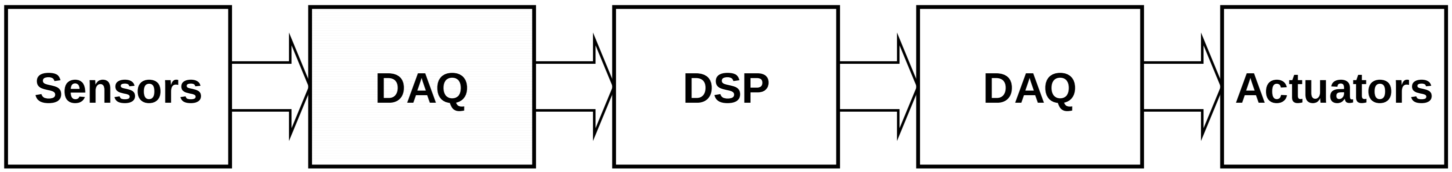
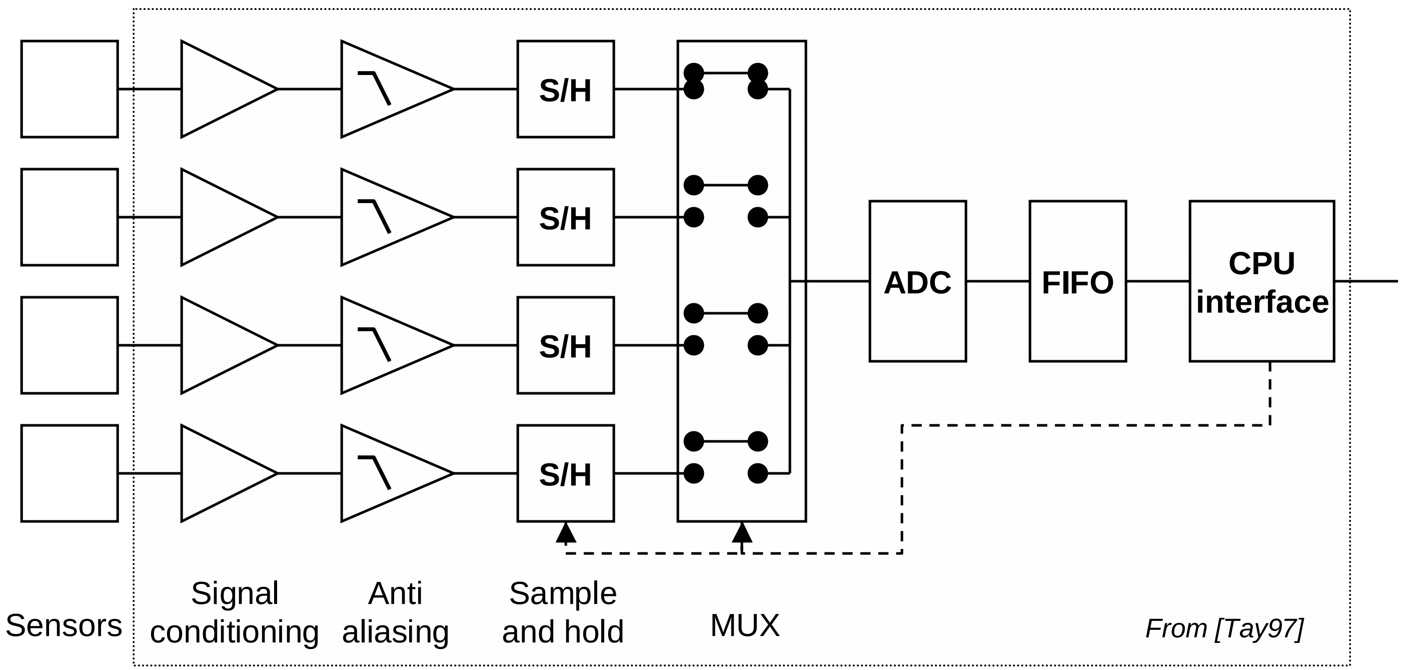
Lecture 6: Data Acquisition I

- **Architecture of DAQ systems**
- **Signal conditioning**
- **Aliasing**

Architecture of data acquisition systems



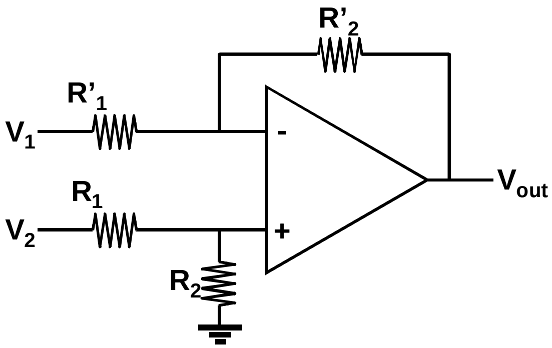


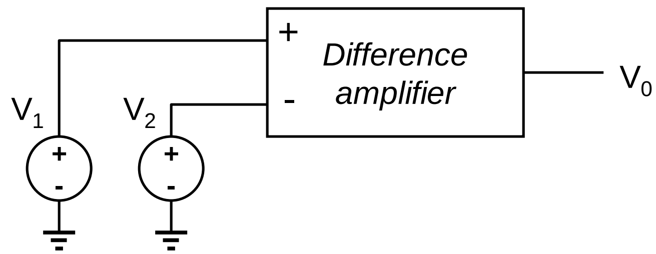
Signal conditioning

- **Instrumentation amplifiers**
- **Filters**
- **Integrators/differentiators (previous lecture)**

Instrumentation amplifiers

- **Consider the difference amplifier we saw in the previous lecture**

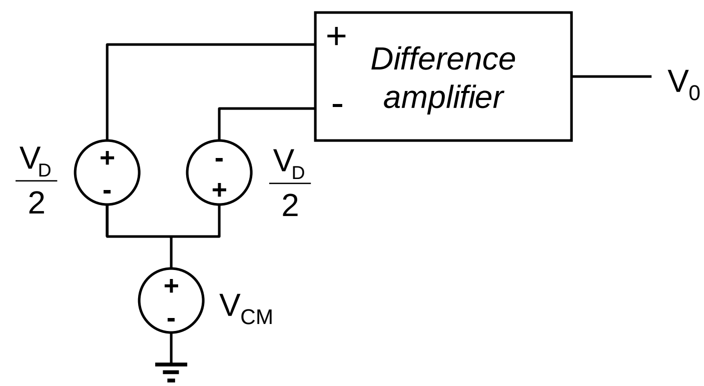




- **We define COMMON-MODE and DIFFERENCE-MODE voltage as**

$$V_{CM} = \frac{V_2 + V_1}{2}$$

$$V_D = V_2 - V_1$$



Instrumentation amplifiers

- **As a result of a mismatch in the resistors ($R'_k \neq R_k$), the differential inputs may not have the same gain**

$$V_0 = G(V_2 - V_1) \overset{R'_k \neq R_k}{=} G_2V_2 - G_1V_1 = G_2\left(-\frac{V_D}{2} + V_{CM}\right) - G_1\left(\frac{V_D}{2} + V_{CM}\right) =$$

$$= -V_D\left(\frac{G_2 + G_1}{2}\right) + V_{CM}(G_2 - G_1) = -V_DG_D + V_{Cm}G_{CM}$$

- **We define COMMON-MODE REJECTION RATIO as**

$$CMRR = 20\log_{10}\left(\frac{G_D}{G_{CM}}\right) = 20\log_{10}\left(\frac{G_2 + G_1}{2(G_2 - G_1)}\right)$$

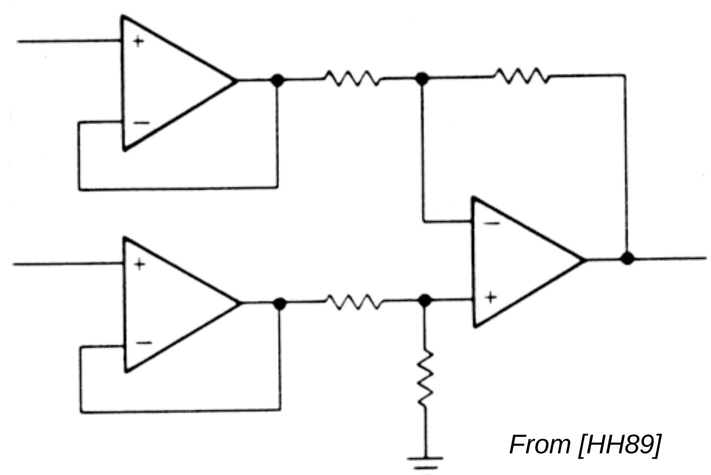
  - CMRR is, in practice, a function of frequency, and its magnitude decreases with increasing frequency

- **An additional shortcoming of the difference amplifier is its LOW INPUT IMPEDANCE**

Instrumentation amplifiers

- **The term INSTRUMENTATION AMPLIFIER is used to denote a difference amplifier with**
  - High gain (recall INA2126 in Lab I)
  - Single-ended output
  - High input impedance
  - High CMRR

- **High input impedance may be achieved by buffering the differential inputs**

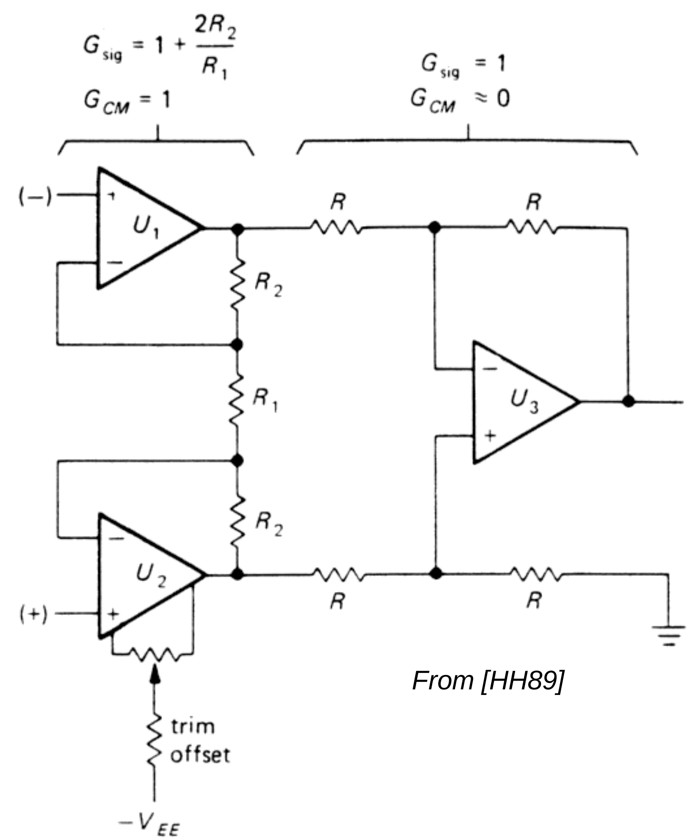


From [HH89]

  - This solution, however, requires high CMRR both in the followers and in the final op-amp
    - Otherwise, since the input buffers have unity gain, all the CM rejection must come in the output op-amp, requiring precise resistor matching

Common mode rejection ratio

- **A better solutions is the "standard" instrumentation amplifier shown below**
  - Input stage provides high G_D and unity G_{CM}
    - Close resistor (R_2) matching is NOT critical
  - As a result, the output op-amp (U_3) does not require exceptional CMRR and resistor matching in U_3 is not critical
  - Offset trimming can be done at one of the input op-amps



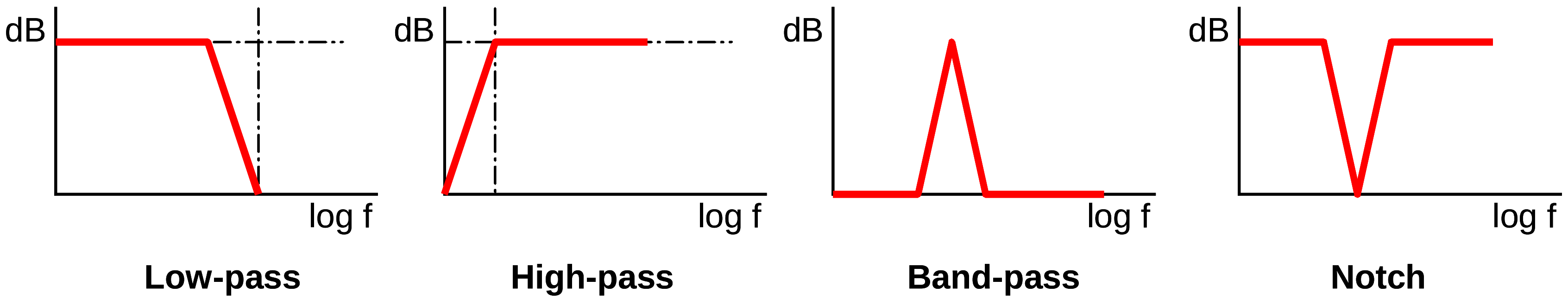
From [HH89]

Filters

- **Filters are used to remove *unwanted* bandwidths from a signal**
- **Filter classification according to implementation**
  - Active filters include RC networks and op-amps
    - Suitable for low frequency, small signal
    - Active filters are preferred since avoid the bulk and non-linearity of inductors and can have gains greater than 0dB
    - However, active filters require a power supply
  - Passive filters consist of RCL networks
    - Simple, more suitable for frequencies above audio range, where active filters are limited by the op-map bandwidth
  - Digital filters
    - DSP is beyond the scope of this course

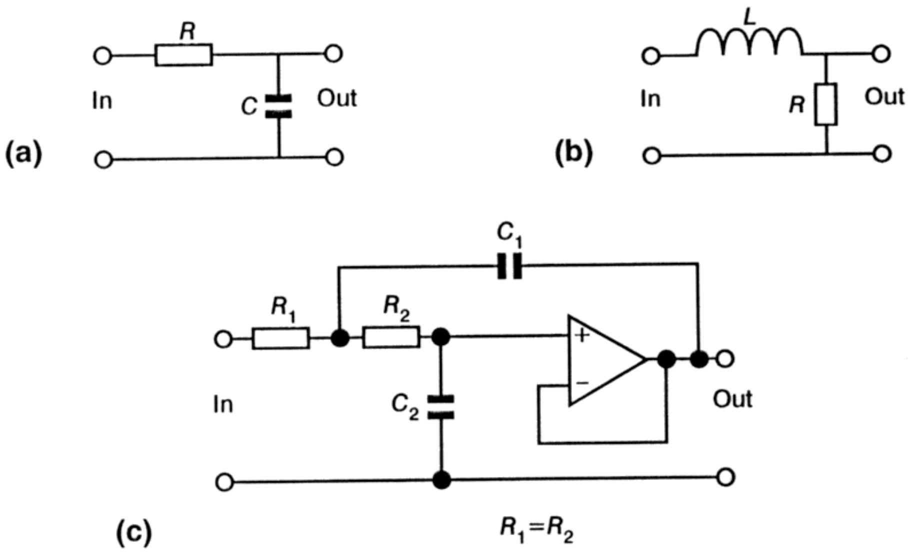
Filters

- **Filter classification according to frequency response**
  - Low-pass filter
  - High-pass filter
  - Band-pass filter
  - Band-stop (Notch)

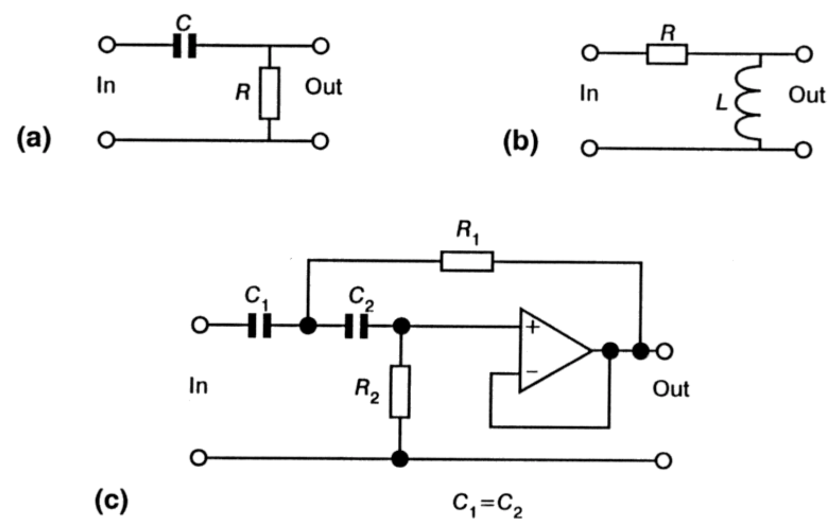


Low- and high-pass filters

- **Low pass filters**
- **High pass filters**



From [Ram96]

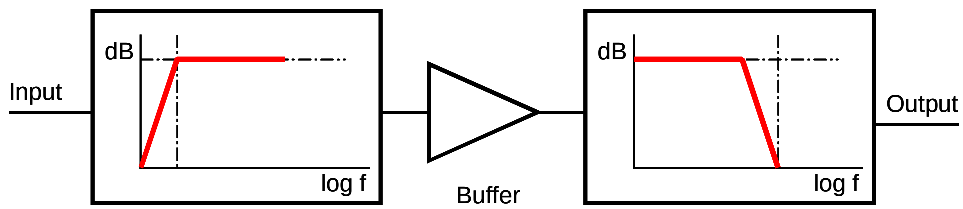


From [Ram96]

Band-pass and band-stop filters

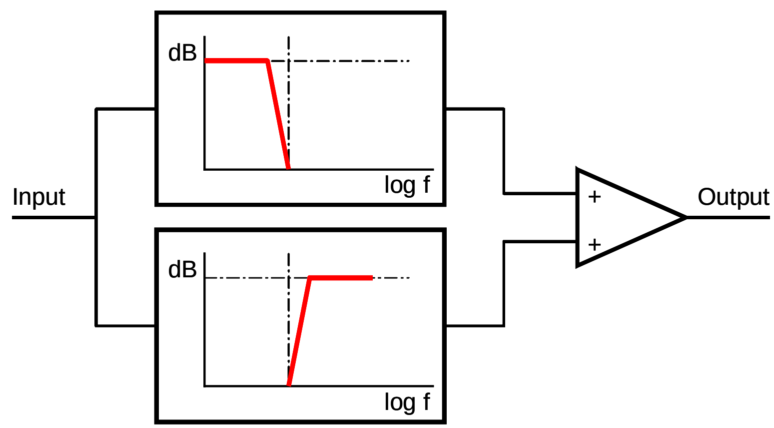
Band-pass

- High-pass and low pass in series
  - High-pass should usually precede
    - Corner frequency of low-pass must then be higher
  - If these are passive filters they should be buffered in between



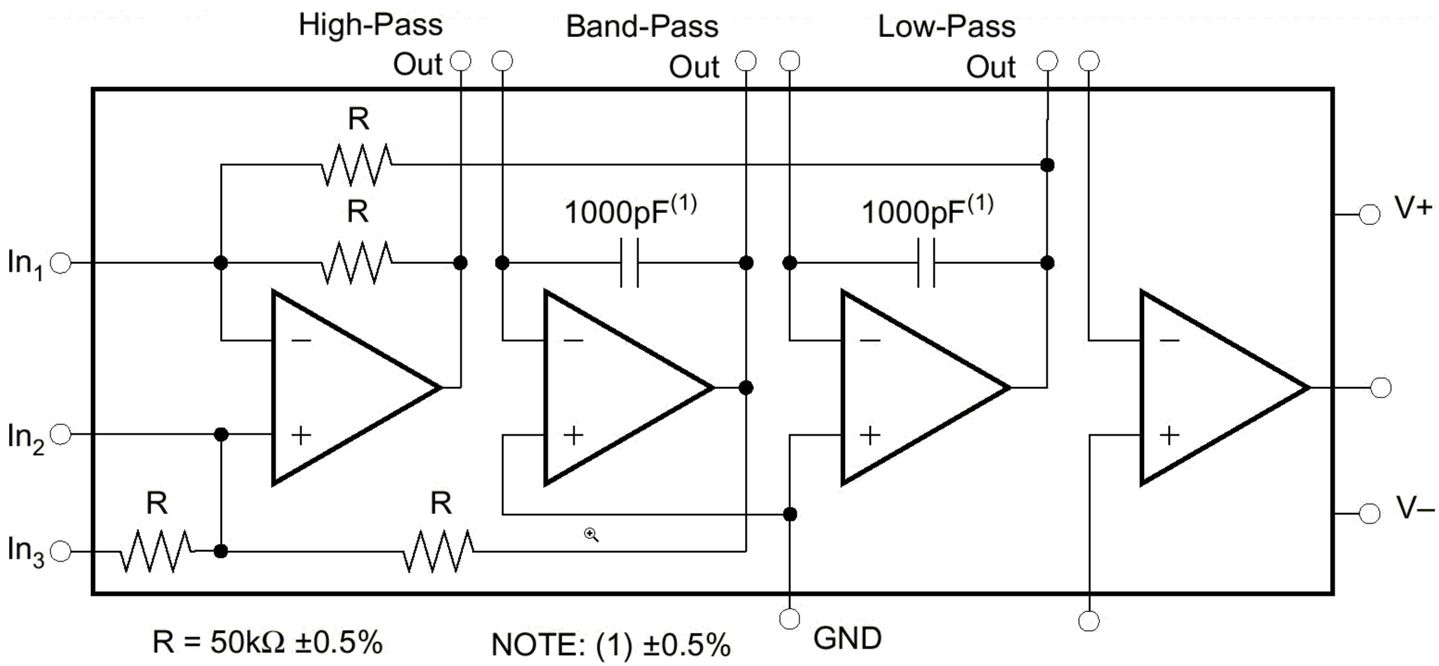
Band-stop

- High-pass and low-pass in parallel followed by a summer
  - Corner frequency of high-pass must be higher



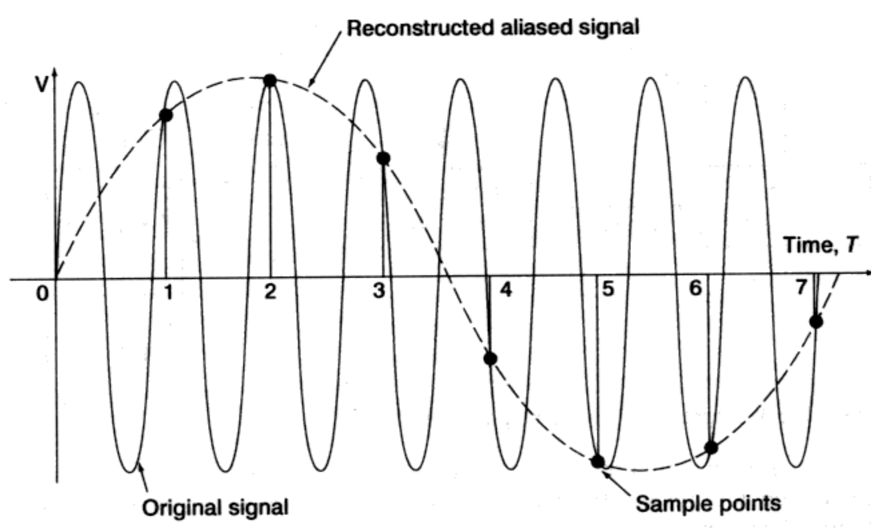
State-variable filters

- **Also known as a Universal Active Filter**
  - Consists of one amplifier and two integrators
  - High-pass, low-pass and band-pass in the same IC
  - Example below: Burr Brown UAF42



Anti-aliasing

- **The sampling theorem**
  - A continuous signal can be represented completely by, and reconstructed from, a set of instantaneous measurements or samples of its voltage which are made at equally-spaced times. The interval $T(=1/F_S)$ between such samples must be less than one-half the period of the highest-frequency component F_{MAX} in the signal
  - In other words: you must sample at least twice the rate of the maximum frequency in your signal to prevent aliasing ($F_S \geq 2F_{MAX}$)
  - The sampling rate $F_S=2F_{MAX}$ is called the Nyquist rate



From [Ram96]

Anti-aliasing

- **The effects of aliasing can also be observed on the frequency spectrum of the signal**
- **In the figures below**
  - F_1 appears correctly since $F_1 \leq F_S/2$
  - F_2, F_3 and F_4 have aliases at 30, 40 and 10Hz, respectively
  - You can compute these aliased frequencies by <u>folding</u> the spectrum around $F_S/2$ or with the expression

$$\text{Alias frequency } \hat{F} = \min\left|kF_S - F\right|_{\forall k \text{ integer}}$$

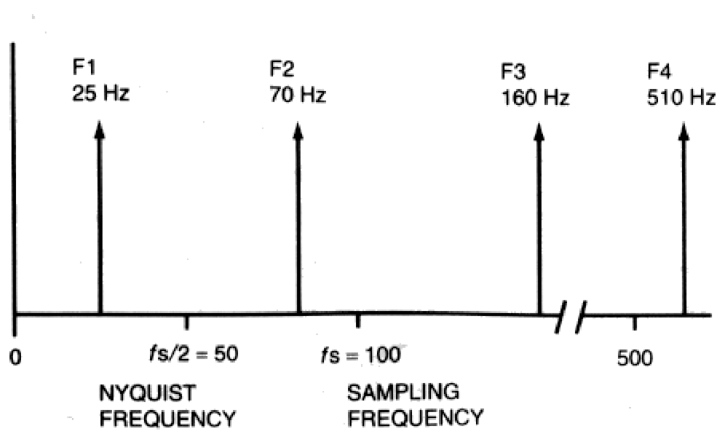
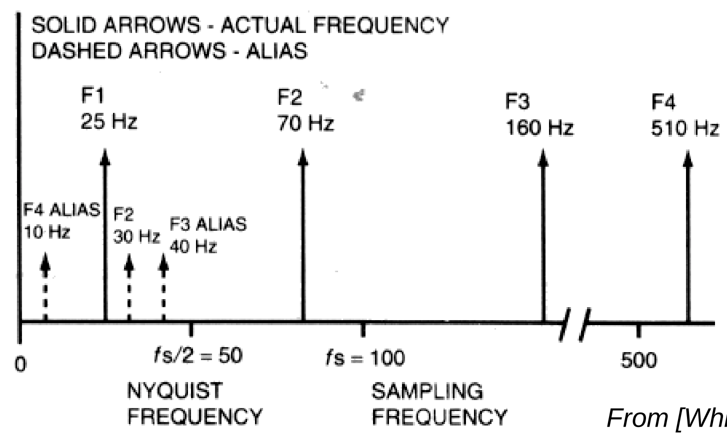


FIGURE 117.5 Spectral of signal with multiple frequencies.

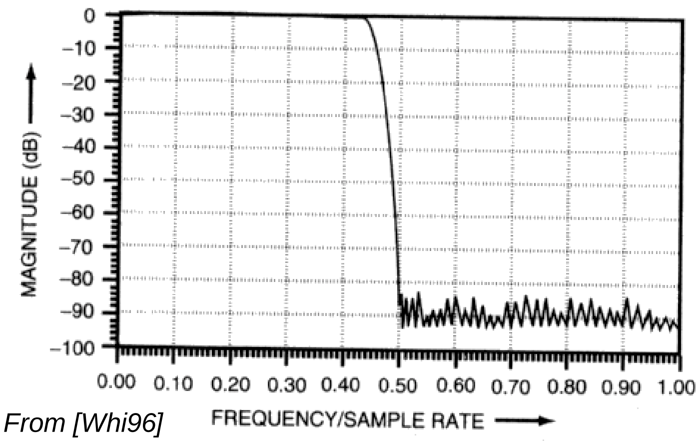


From [Whi96]

FIGURE 117.6 Spectral of signal with multiple frequencies after sampled at $fs = 100$ Hz.

Anti-aliasing filters

- **An anti-aliasing filter is a low-pass filter designed to filter out frequencies higher than the sampling frequency**
  - An anti-aliasing filter should have
    - Steep cut-off and
    - Flat response in the frequency band



From [Whi96]

- **Typical filters are:**
  - **Butterworth**: flattest response in the frequency band but phase shifts well below the break frequency
  - **Bessel**: phase shift proportional to frequency, so the signal is not distorted by the filter
    - Recommended for anti-aliasing if it is important to preserve the waveform
  - **Chebyshev**: steepest cut-off but it has ripples in the band-pass

References

[Whi96] J. C. Whitaker, 1996, The Electronics Handbook, CRC Press

[Ram96] D. C. Ramsay, 1996, Principles of Engineering Instrumentation, Arnold, London, UK

[Tay97] H. R. Taylor, 1997, Data Acquisition for Sensor Systems, Chapman and Hall, London, UK.

[HH89] P. Horowitz and W. Hill, 1989, The Art of Electronics, 2nd Ed., Cambridge University Press, Cambridge, UK